NASA CR- 66093

Schjeldahl / ADVANCED PROGRAMS DIVISION

G. T. SCHJELDAHL COMPANY • NORTHFIELD, MINNESOTA 55057 • PHONE 507-645-5633

[redacted]

N66 24384

N66 24384 (ACCESSION NUMBER)	(THRU)
49 (PAGES)	1 (CODE)
CR-66093 (NASA CR OR TMX OR AD NUMBER)	02 (CATEGORY)

FACILITY FORM 602

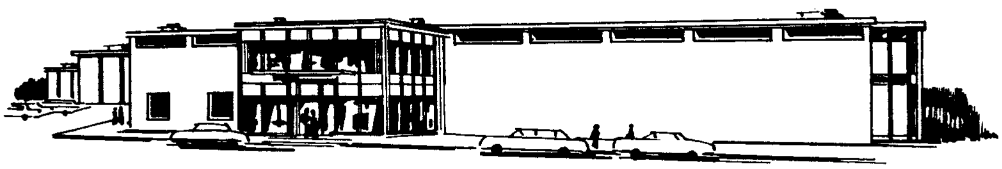
GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65



PUTTING TOMORROW'S MATERIALS TO WORK TODAY

G. T. SCHJELDAHL COMPANY
Northfield, Minnesota

INVESTIGATION OF THE FLIGHT CHARACTERISTICS OF FREE FLYING AERODYNAMICALLY SHAPED BALLOONS

Final Report on Contract NASI-5271

Submitted To:

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Prepared By:

Clinton V. Eckstrom

Clinton V. Eckstrom
Project Engineer

Approved By:

R. J. Slater

R. J. Slater
Program Manager

E. A. Basquin

E. A. Basquin
Report Editor

TABLE OF CONTENTS

LIST OF FIGURES

FIGURES

LIST OF TABLES

SUMMARY

24384

The investigation of the flight characteristics of free-flying aerodynamically shaped balloons included a literature study, an aerodynamic analysis, and fabrication and flight test of six streamlined balloons. A small streamlined balloon design was achieved which resulted in stable, nose-up flight from ground launch to float altitude. All the large streamlined balloons of 150 cubic foot volume failed to fly at zero angle of attack but rather were stable at near horizontal position during the visible portion of the flight. Variations in flight stability did occur at higher altitudes as determined from radar plot board data and as predicted by the force equilibrium equations presented.

Author

1.0 INTRODUCTION

At the present time there is extensive interest in the capability of lightweight balloons to move through the atmosphere without extraneous or induced movements perpendicular to the direction of the flight path. Aerodynamically shaped balloons, used for many years as powered airships or as tethered balloons, are designed primarily to give smooth airflow characteristics to a low drag body. Both powered airships and tethered balloons fly horizontally, and it was the purpose of this investigation to determine if similarly shaped, lighter-than-air balloons would rise vertically through the atmosphere along a stable flight path.

A small, 9-foot long, model capable of attaining 25,000 feet altitude was successfully flown several times. Larger models capable of attaining 50,000 to 60,000 feet altitude did not have stable flight characteristics. The literature study revealed that stability is also a major problem for airships and tethered balloons. Equations for force and moment equilibrium are presented, but have not been confirmed by flight test.

2.0 REVIEW OF LITERATURE

2.1 GENERAL

The investigation of free-flying, aerodynamically shaped balloons began with a review of literature on Airships, Dirigibles, Blimps and Kite balloons. Of primary interest was information on drag and stability as a function of system shape, volume, and fin size.

2.2 AIRSHIPS

Airships or dirigibles are defined as self-propelled, lighter-than-air craft with a means of controlling the direction of flight. They are usually classed as rigid, semirigid, or nonrigid. Most of the literature relating to airships is dated in the years 1915 to 1932 when considerable research was conducted by various government agencies. There were 62 documents concerning airships published by NACA during the period 1915 to 1949. The disaster of the Hindenberg and the increased capabilities of heavier-than-air aircraft resulted in the discontinuation of research on large airships of the Akron, Shenandoah, and Zeppelin types. It was found that, with elevators and rudders neutral, the Shenandoah was stable at an angle of attack of 70 degrees (reference 1). Extremely high rudder and elevator angles are needed to maintain zero angle of attack. Tests of a 1/40 scale model of the U. S. Airship "Akron" indicated the vehicle is unstable at angles less than 24 degrees (reference 2).

Drag coefficients based on volume increased from 0.019 to 0.024 when tail surfaces were added to the airship "Akron". The surface area of these tail fins is quite small relative to the surface area of the main body.

2.3 BLIMPS

Airships of the nonrigid type, called blimps, are still in limited use, and a few reports concerning them were reviewed. Most of the blimps were of the Navy Class C shape or close approximations thereof. No literature relating to tests of stability of such vehicles was found.

2.4 KITE BALLOONS

Aerodynamically shaped tethered balloons, referred to as kite balloons, are used extensively to suspend instruments in the atmosphere at desired levels. The balloons are attached to the tether lines so as to be at some angle of attack to horizontal winds. In wind conditions the balloons provide considerable aerodynamic lift and a minimum drag, and therefore, are able to keep the tether lines nearly vertical despite wind conditions. Most of the information available on tethered aerodynamically shaped balloons also related to Navy Class C shapes or modifications thereof.

2.5 DRAG OF STREAMLINED BODIES

Several references (3 and 4) were found which presented the drag of the Navy Class C airship hull as a function of fineness ratio. The drag data are usually presented in two ways. The first is based on frontal area only and indicates that an airship of fineness ratio f = 2.1:1 has the least total drag based on frontal area. However, of more importance to most applications is the drag per unit of volume. Information presented in the above mentioned references indicated the minimum drag per unit volume occurs at a fineness ratio of 4.5 to 4.62 for the C-Class shape. The drag coefficient (based on volume) of the C-Class airship hull of fineness ratio of 3:1 is shown to be 0.0205; this is without fins. Reference 5 on tethered streamlined balloons indicated a drag coefficient of 0.12 for a C-Class balloon with Y-type inflated tail fins. These data are taken from a wind tunnel study by Bairstow (6).

From these data, it is apparent that the drag of the inflated fins is greater than the drag of the streamlined hull.

2.6 DYNAMIC STABILITY

The literature concerning large airships revealed that they were not stable at zero angle of attack, and that straight flight was achieved by means of movement of control surfaces on the tail fins. An example of this is listed in reference 7 which indicated the ZMC-2 airship would spin out in a turn and that the Shenandoah and the Army AC airships were unstable. The stability in flight direction of the blimp-type airships is also maintained by means of the tail fin control surface.

Tethered streamlined balloons are also dynamically unstable under certain tether line conditions (5) and at high wind velocity conditions. Of course these balloons are purposely tethered at a small angle of attack (5 to 10 degrees) to provide aerodynamic lift from winds.

3.0 AERODYNAMIC ANALYSIS

3.1 BACKGROUND

The investigation was concerned primarily with a determination of the flight characteristics of free-flying, aerodynamically shaped balloons such as the airships, blimps and tethered kite balloons presently in use. The purpose of the investigation was to determine if aerodynamically-shaped balloons would rise vertically through the atmosphere in a nose-up position at zero or near zero angle of attack. A free flying streamlined balloon which is stable at zero angle of attack would have little or no aerodynamic lift and minimum drag for an extremely fast rise rate.

3.2 STATIC STABILITY - EQUILIBRIUM OF FORCES

If a system is to be in equilibrium, the resultant force and the resultant couple must be equal to zero, and the conditions for equilibrium are:

$$R = \Sigma F = 0 \tag{1}$$

$$C = \Sigma M = 0 \tag{2}$$

where R is the resultant force, C is the resultant couple, F is an individual force, and M is an individual moment.

It is convenient to describe the force system in rectangular coordinates and the general equations of equilibrium become:

$$\Sigma F_x = 0 \tag{3}$$

$$\Sigma F_y = 0 \tag{4}$$

$$\Sigma F_z = 0 \tag{5}$$

$$\Sigma M_x = 0 \tag{6}$$

$$\Sigma M_y = 0 \tag{7}$$

$$\Sigma M_z = 0 \tag{8}$$

For simplification purposes we will consider only the vertical (x, y) plane which leaves us with the following equations of:

$$\Sigma F_x = 0 \quad (9)$$

$$\Sigma F_y = 0 \quad (10)$$

$$\Sigma M_z = 0 \quad (11)$$

For a heavier-than-air vehicle such as a bomb or a missile the point about which the moments are zero is the center of gravity (c.g.). The c.g. location can be determined by calculation or by balance measurement. The buoyant force of the displaced air is automatically included in the location of c.g. by balance measurement and is generally too small to be of significance in calculations.

For a lighter-than-air vehicle, such as the streamlined balloons under consideration here, the buoyant force (B) may be several times larger than the total weight of the balloon (W) and the inflation gas. The summation of forces in the vertical direction, ΣF_y, will be zero, as required by equation 10, when a downward force equal to the free lift is applied to the balloon. In flight this downward force will be the vertical component of the resultant aerodynamic force (Q_y).

$$\Sigma F_y = B - W - Q_y = 0 \quad (12)$$

Under static conditions there are no forces in the horizontal (x) direction:

$$\Sigma F_x = 0 \quad (13)$$

The moment forces on the streamlined balloon will be zero, as required by equation 11, when the downward force (Q_y) is applied at a distance (c) from the center of buoyancy as shown in Figure 1.

Then

$$\Sigma M_z = Bc - W (c + d) = 0 \quad (14)$$

$$c = \frac{d}{(B/W - 1)} \quad (15)$$

where d is the distance between the center of buoyance and the center of gravity.

A helium-filled, streamlined balloon is statically balanced in the horizontal position when the downward force is applied at the balance point designated as the center-of-free-lift.

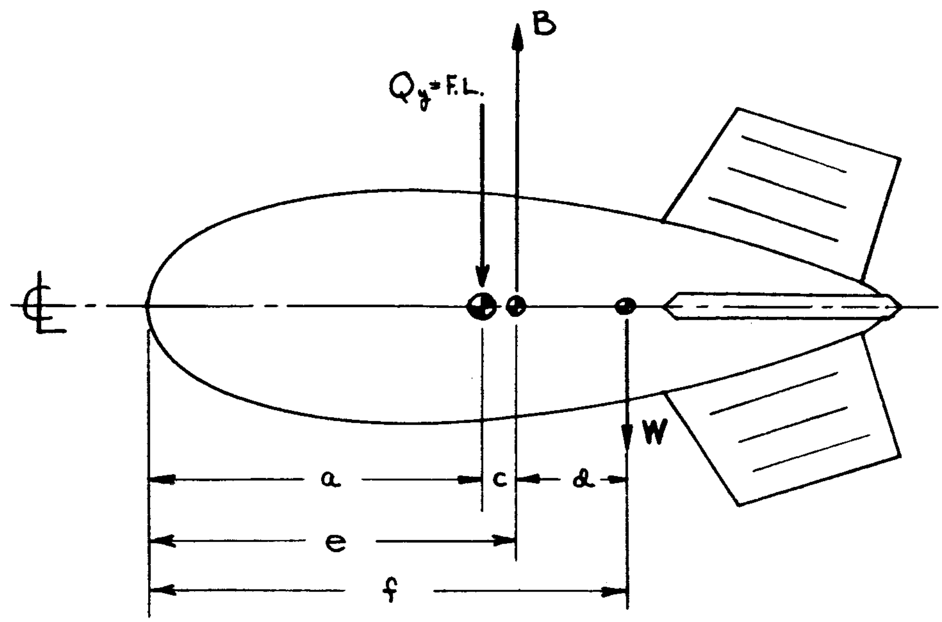


FIGURE 1

Forces and Their Locations
On A Statically-Balanced,
Streamlined Balloon

As indicated previously the vertical component of the resultant aerodynamic force (Q_y) will balance the balloon free lift during flight.

If the streamlined balloon flies at a stable angle of attack, that angle will be such that the aerodynamic force (Q_y) will pass through the balloon center-of-free-lift. From equation 15 it is seen that the location of the center-of-free-lift changes during flight as the buoyance decreases with increasing altitude. This is based on the fact that the location of the center of buoyancy remains constant for a balloon of fixed shape. Now as the balloon buoyancy decreases with altitude the center-of-free-lift moves forward (for a ballon on which the center of gravity is located aft of the center of buoyancy). As the center-of-free-lift does move forward the balloon flight angle will decrease until a new condition of equilibrium of forces and moments is attained. At some altitude the center-of-free-lift will move forward of all possible locations of the resultant aerodynamic force and the streamlined balloon will fly at zero angle of attack if it is basically aerodynamically stable, or oscillate about its equilibrium angle if this is other than zero angle of attack.

Moments on airships and blimps have been measured at the vehicle center of buoyancy. Because airships and blimps travel at float altitudes there is no free lift. Also the airship center of gravity must be located at or very near the center of buoyancy for static stability at zero angle of attack. These conditions are considerably different than those imposed on the free flying airships of interest here as it is the free lift which is the propelling force for these balloons.

3.3 VERTICAL RISE RATE

The resultant aerodynamic force in the vertical direction is equal to the buoyant force minus the weight and goes to zero as the balloon approaches float altitude. The resultant aerodynamic force is also a function of shape coefficient and relative velocity. The shape coefficient changes with angle of attack and therefore the vertical rise rate is directly dependent on the equilibrium angle of attack the streamline balloon assumes. The fastest rise rates will be attained when the balloon is stable at zero angle of attack where the system has the lowest shape coefficient.

3.4 BALLOON RESPONSE TO HORIZONTAL WINDS

If the center of gravity of the streamlined balloon is coincident with the center of buoyance, the balloon will be statically stable at any angle, but dynamically stable at zero angle of attack only (assuming we are working with an aerodynamically stable balloon system). Such a streamlined balloon will be a pure drag device which is always at zero angle of attack to the relative air velocity. The response to horizontal winds will be strictly a function of its mass, the mass of the displaced air, and the square of the rise rate. This is the same as the response of presently used spherical wind sensing balloons.

If the center of gravity of the streamlined balloon remains behind the center of buoyancy, the balloon will have a stabilizing moment in the vertical direction even when the unit is subject to a horizontal wind shear. The resultant angle of attack of the balloon will be such that the moment due to buoyancy is balanced by the moment due to aerodynamic forces on the balloon at the center of pressure. In this case the response of the shaped balloon to the wind will be better than that of a pure drag device (of the same size and weight) but the balloon will still retain some response lag.

4.0 EXPERIMENTAL FIN DESIGNS AND TESTS

4.1 BACKGROUND

A small streamlined balloon shape as outlined in Figure 2 was established at the beginning of the program for the purpose of investigating fin designs. The requirements for fins were that they be as lightweight as possible but also large and rigid.

4.2 INFLATED FIN DESIGNS

Most aerodynamically shaped balloons use inflated fins for stabilization purposes. These fins are usually fabricated separately and then attached to the main balloon body.

4.2.1 First Fin Design

A fin design which included the fin as a part of the main balloon gore was established for the purpose of determining if integral fins could be used to reduce weight. Pertinent data are given in Table 1. The integral fin design was essentially a failure as there was no rigidity between the fin and the main body. In addition the various tubular sections of the fin were made without baffles and this resulted in loss of rigidity between tubular sections. The balloon was flight tested but the fins folded over immediately and the balloon ascended in a near horizontal position which indicated that its stable angle of flight was near ninety degrees.

4.2.2 Second Fin Design

The second fin design utilized separate fins with a wide base, and baffles for fabrication of the tubular sections. The first fins fabricated to this design were also considered unsatisfactory as there was considerable leakage. However, a redesign as shown in Figure 2 utilized a base plate which was fastened to the main body over the entire base area and essentially eliminated leakage. The baffle plates were also lengthened and widened to provide additional rigidity between tubular sections. Pertinent balloon data are presented in Table 2. A ballast of 50 grams was placed in the nose of the streamlined balloon to locate the center of gravity near the center of buoyancy. When flight tested, this streamlined balloon ascended in a nose-up position at a very rapid rise rate. Visual observations and movie film indicated excellent stability about zero angle of attack during the entire flight. The inflated fins remained rigid as required during the flight test. Later, an identical balloon with the 50-gram ballast placed in the tail flew equally well.

4.3 NONINFLATED FINS

Methods of constructing non-inflated fins were also investigated. Of special interest was the possibility of using a rigid fin outline with a single layer of material for the actual fin. Rigid plastic rods or tubes were considered as a method of attaining the desired fin outline.

The requirement that total balloon weight be as low as possible established weight as the criteria for comparison of inflated and rigid fin systems.

Several plastic rods and tubes as listed in Table 3 were purchased for evaluation. The inflated fins had a weight of approximately 30 grams for an outline length of 60 inches. This is 0.0132 pounds/foot. The only plastic material which could approach this was 3/16 inch diameter nylon rod with a weight of 0.014 pounds/foot. The nylon rod was not one of those considered to have sufficient stiffness for this purpose. A fin outline was made of Delrin rod and was found to be of sufficient stiffness if properly held at the ends. Because of the extra weight associated with

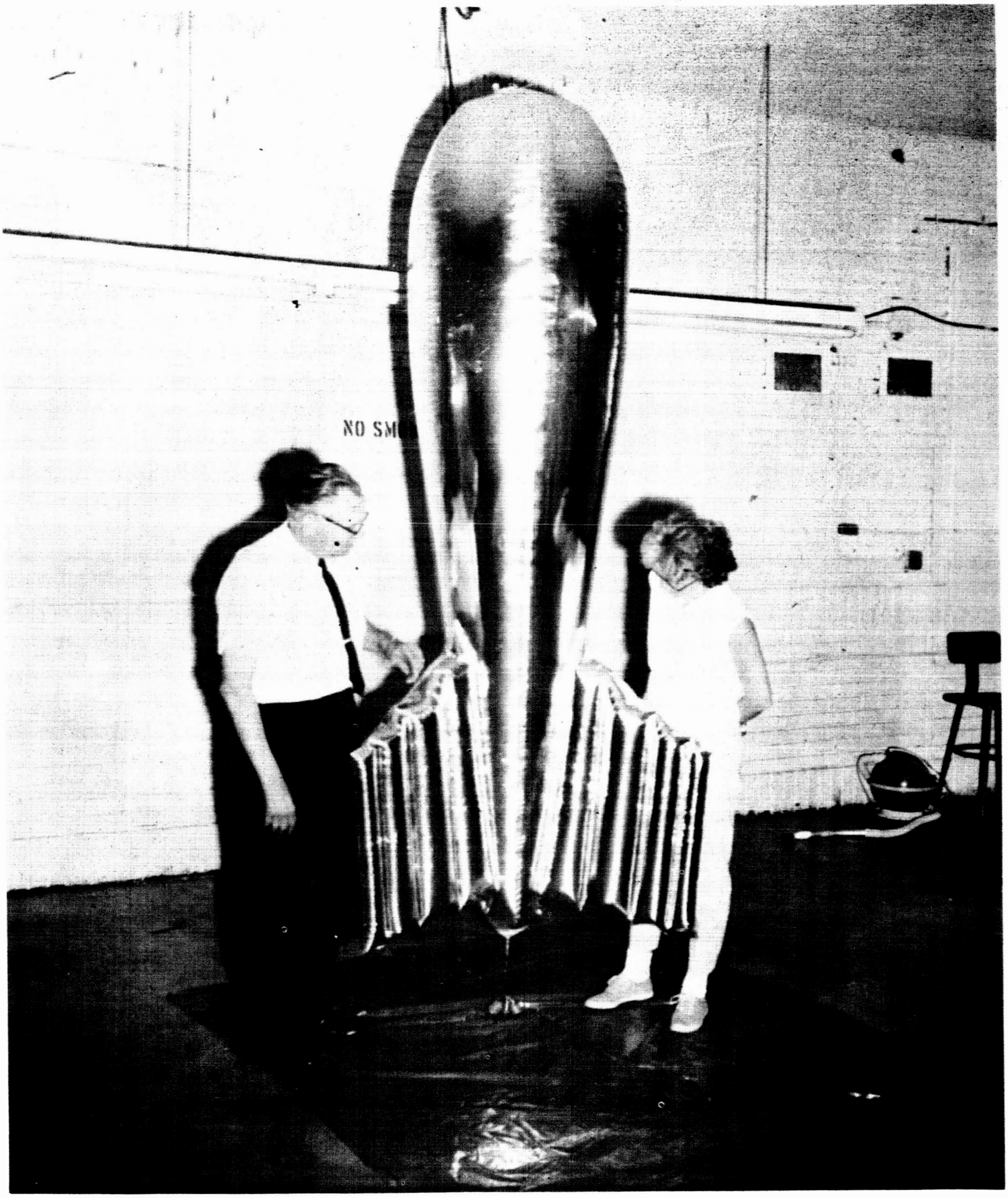


FIGURE-2 SMALL STREAMLINED BALLOON ESTABLISHED FOR FIN DESIGN STUDIES

the stiffening rods, no further consideration was given to the fin outline method of construction at that time. However, the rigid fins concept is still of importance because of possible drag reduction and reduced cost possibilities.

TABLE 1: EXPERIMENTAL BALLOON FLIGHT TEST NO. 1

Date: August 17, 1965

Airship Data:

Length	108.0 inches
Center of Gravity	58.5 inches
Center of Free Lift	37.5 inches
Center of Buoyancy	53.1 inches
Weight	139.1 grams
Free Lift	440.0 grams
Total Lift	579.1 grams
Volume (based on lift)	19.4 cubic feet

Results:

Balloon was stable at near 90 degree angle of attack. Balloon ascended slowly in near horizontal position.

TABLE 2: EXPERIMENTAL BALLOON FLIGHT TEST NO. 2

Date: August 20, 1965

Airship Data:

Length	108.0 inches
Center of Gravity	61.5 inches
Center of Free Lift	45.0 inches
Center of Buoyancy	49.0 inches
Weight	162.3 grams
Free Lift	504.5 grams
Total Lift	666.8 grams
Volume (based on lift)	22.3 cubic feet
Inflated Fin Size: (three used)	
Height	18 inches
Base Length	27 inches
Tip Length	22 inches

Special Note: 50 grams ballast weight was located in nose of balloon to shift center of gravity to 47 inches aft of nose.

Results: Balloon ascended nose up at a rapid rise rate - was very stable at zero or near zero angle of attack.

TABLE 3: PLASTIC RODS AND TUBES EVALUATED FOR USE AS FIN REINFORCEMENT

	MATERIAL	SIZE (inches)	WEIGHT PER FOOT LENGTH (pounds)
1.	Delrin Square Rod		
2.	Delrin Rod	1/4 dia & 3/8 sq.	0.030
3.	Nylon Rod	3/16 diameter	0.014
4.	Teflon Rod	3/16 diameter	0.028
5.	Polyethylene Rod	1/4 diameter	0.020
6.	Cast Acrylic Rod	1/4 diameter	0.026
7.	Hi Density Polyethylene Rod	1/4 diameter	0.025
8.	Lexan Polycarbonate Rod	1/4 diameter	
9.	Polypropylene Rod	1/4 diameter	0.020
10.	Cellulose Acetate Butyrate Tubing		
11.	Extruded Polystyrene Tubing	1/4 O.D. & 1/8 I.D.	

5.0 FLIGHT TESTS

5.1 FLIGHT TEST BALKOONS

Six streamlined balloons of the Class-C shape were fabricated for flight test at NASA, Wallops Station, Wallops Island, Virginia. Three fineness ratios and three fin sizes were used. The fineness ratios were 2, 3, and 4 to 1 and the inflated fin sizes were 7, 10, and 13 square feet each. Pertinent data relating to these streamlined balloons are presented in Table 4, and a photo of balloon number 1 is presented in Figure 3. The balloon shapes were determined using equation 1 which is from reference 8.

$$y = \frac{(n + m)^{n + m}}{2fn^n m^m} \frac{x^n}{L^{n + m - 1}} (L - x)^m \tag{16}$$

where:

x is ordinate direction

y is absissa direction

L is total airship length in x direction

f is fineness ratio

n is dimensionless coefficient = 0.30

m is dimensionless coefficient = 0.56

The official offsets for a Navy Class C airship are given in Table 2. The resulting shapes from equation 16 and Table 2 are nearly identical as shown in Figure 4.

It was determined early in the flight test program that the C-Class balloons would not rise vertically at zero angle of attack. Therefore, only four of the original six balloons were flight tested. One small balloon which had been flown earlier in fin design studies, and was known to be stable, was flight tested. (See Figure 2). This was balloon number 7 which flew in flight test number LC-2508. The sixth flight test was conducted with a streamlined balloon designed with the intent of locating the center of buoyancy as far forward as possible. This is balloon number 8 shown in Figure 5, which is described as a hemisphere-cone shape with a 4:1 fineness ratio. This balloon had four, extra large fins, one of which tore the main balloon body shortly after launch on flight test LC-2511. The fin failure is attributed to the extremely large loads applied to them. This hemisphere-cone balloon has since been redesigned to include fin reinforcements attached across the outer ends of the fins to prevent bending of fins due to aerodynamic loads.

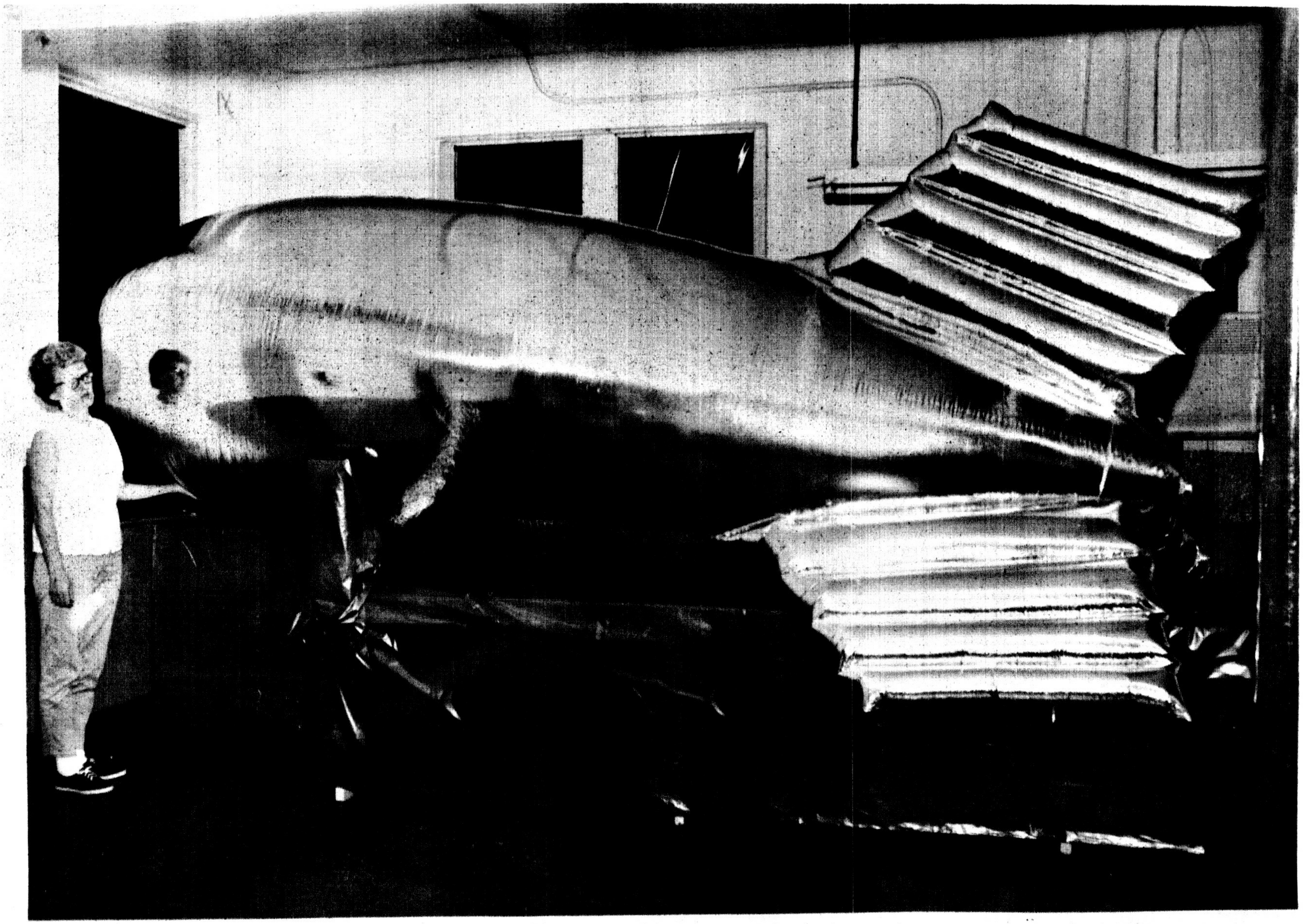


FIGURE-3 CLASS-C STREAMLINED BALLOON OF FINENESS RATIO 3:1 WITH MEDIUM SIZE FINS

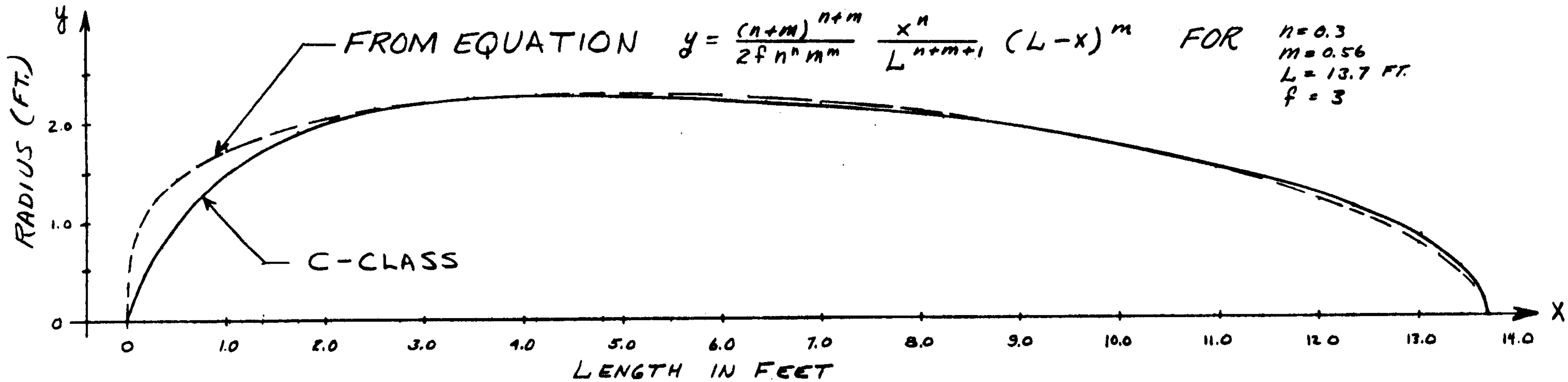


FIGURE 4: COMPARISON OF SHAPES RESULTING FROM USE OF OFFSETS FOR C-CLASS AIRSHIP AND EQUATION FROM REFERENCE 8

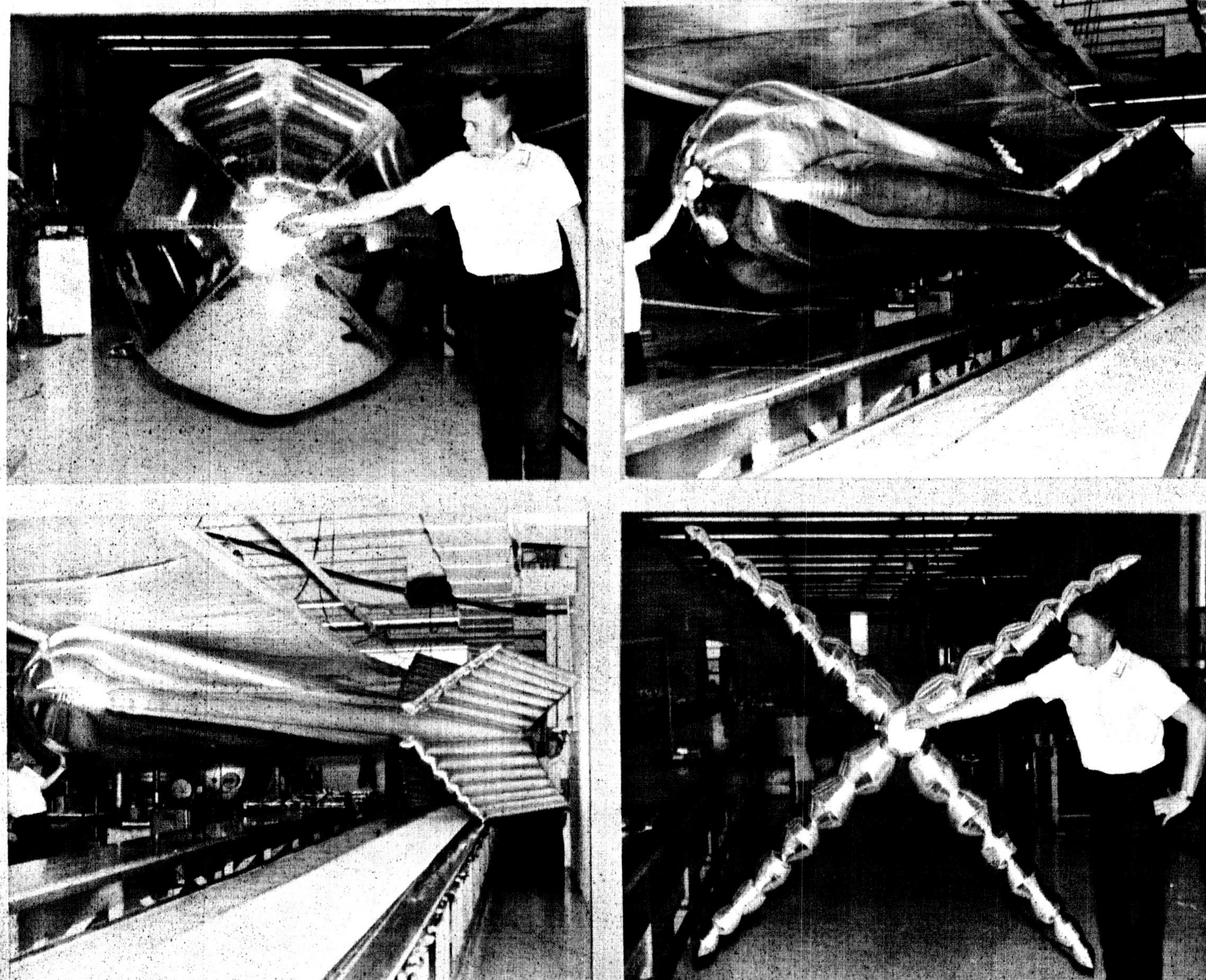


FIGURE-5 HEMISPHERE-CONE STREAMLINED BALLOON OF FINENESS RATIO 4:1 WITH EXTRA LARGE FINS

TABLE 4

STREAMLINED BALLOON DATA

BALLOON NUMBER	1	2	3	4	5	6	7	8
Balloon Shape								
a) C-Class	x	x	x	x	x	x		
b) Modified C-Class							x	
c) Hemisphere-cone								x
Fineness Ratio	3:1	3:1	3:1	4:1	2:1	3:1	4:1	4:1
Length (L) in Feet	13.7	13.7	13.7	16.5	10.4	15.0	9.0	20
Volume of Body (Ft^3)	150	150	150	150	150	200	--	150
Number of Fins	3	3	3	3	3	3	3	4
Fin Area Each (Sq.Ft.)	7	10	13	10	10	10	3	18
Total Lift (Lbs.)	9.42	10.00	10.62	9.50	9.21	13.27	1.49	11.863
Weight (lbs.)	0.90	1.00	1.11	1.00	1.22	1.08	.51	2.315
Free Lift (lbs.)	8.52	9.00	9.51	8.50	7.99	12.19	.98	9.548
Center of Gravity*	.582L	.620L	.650L	.602L	.548L	.667L	.398L	.521L
Center of Buoyancy	.484L	.503L	.504L	.501L	.468L	.498L	.419L	.428L
Center of Free Lift	.475L	.490L	.486L	.490L	.456L	.484L	.430L	.406L

* Center of gravity of balloon skin only, does not include mass of inflation gas.

TABLE 5

Offsets For C-Class Airship (Reference 4)

x/l	2y/t
0	0
0.0125	0.200
0.0250	0.335
0.0500	0.526
0.0750	0.658
0.100	0.758
0.125	0.835
0.150	0.887
0.200	0.947
0.250	0.982
0.300	0.998
0.35	0.999
0.40	0.990
0.50	0.950
0.60	0.885
0.70	0.790
0.80	0.665
0.90	0.493
0.95	0.362
0.98	0.225
1.00	0

TABLE 6

FLIGHT TEST DATA

WALLOPS FLIGHT NUMBER	BALLOON NUMBER	RADAR	DATE	TIME	REMARKS
LC-2503	2	FPS-16	10/19/65	1035	Small air scoops added to tail section. Lower airscoops fluttered, top airscoop did not. 0.21 pounds ballast in nose.
LC-2504	3	FPS-16	10/20/65	1000	Large air scoops added to tail section, and all scoops fluttered in flight. No ballast added.
LC-2507	1	FPS-16	10/20/65	1520	Balloon shape was modified by changing 3 gore seams to a straight line from the nose to the tail fin. (0.21 pounds ballast is nose.)
LC-2508	7	FPS-16	10/25/65	1100	Good flight. Small streamlined balloon originally used for fin design studies.
LC-2509	6	FPS-16	11/02/65	1055	Modified shape to be same as that of small balloon in flight LC-2508.
LC-2511	8	FPS-16	12/07/65	1400	Fin tore during launch - no test.

5.2 FLIGHT TEST LC-2503

The first streamlined balloon flight test, LC-2503, was with balloon number 2, which is a C-Class shape of 3:1 fineness ratio with three fins of 10 square foot area each. Three small airscoops were added to the balloon, one each between fins. These airscoops were 30 inches long with a 3:1 inlet to exit area (R inlet = 10 inches). This streamlined balloon flew in a near horizontal position during all of the visually recorded portion of the flight. Radar plot board data were recorded for eleven minutes during which time the balloon rose to 5,825 feet altitude at an average rate of rise of 8.8 feet per second. The flight path was somewhat circular in motion with the primary direction of travel being with the wind. The balloon performed three loops during the eleven minutes the track was recorded.

5.3 FLIGHT TEST LC-2504

The second streamlined balloon flight test, LC-2504, was with balloon number 3 which was the same as the balloon on the first flight test except that it had larger fins. Each fin had 13 square feet of area rather than 10. In addition larger airscoops were installed between fins. These airscoops were 40 inches long with a 4:1 inlet to exit area ratio (R inlet = 20 inches). Radar plot board position data at one minute intervals were obtained for most of the 77 minutes of flight. During this time the balloon reached an altitude of 57,000 feet. The rise rate as determined from the plot board data indicates considerable variation between individual position points. Because the accuracy of individual position points is questionable, the average rise rate was determined for various altitude increments as shown in Figure 6. This plot shows that the rise rate was continually increasing with a large increase just before float altitude. It is interesting to note that the rise rate during the first 5,000 feet is essentially the same as that of the balloon on the first flight test.

This balloon also began flight in a horizontal position and maintained that position during the visible portion of the flight. However, it obviously decreased drag area during flight which indicates changing stability characteristics and angle of attack with altitude as suggested in section 3.2. The maximum average rise rate was 22 feet per second which occurred from 40 to 53 thousand feet altitude. This maximum rise rate is better than double the initial rise rate even though the balloon is near its float altitude of 57,400 feet.

5.4 FLIGHT TEST LC-2507

The third streamlined balloon flight test, LC-2507, was with balloon number 1, modified to reduce the aerodynamic smoothness of the main body. The balloon was initially a C-Class shape of 3:1 fineness ratio. This was modified by changing 3 of the 6 gore seams to straight line segments from near the nose to the tail. This change had the effect of changing the balloon outline from a smoothly changing surface to one made up of conical sections. No airscoops were added and this balloon had small fins of only 7 square foot area each. This streamlined balloon also rose in a near horizontal position during the visual portion of the flight. The average rise rate during the first 10,000 feet of altitude was 10 feet per second or essentially the same as the first two streamlined balloons flight tested. However, at 10,500 feet altitude an abrupt change in rise rate occurred as shown in Figure 7. The rise rate became

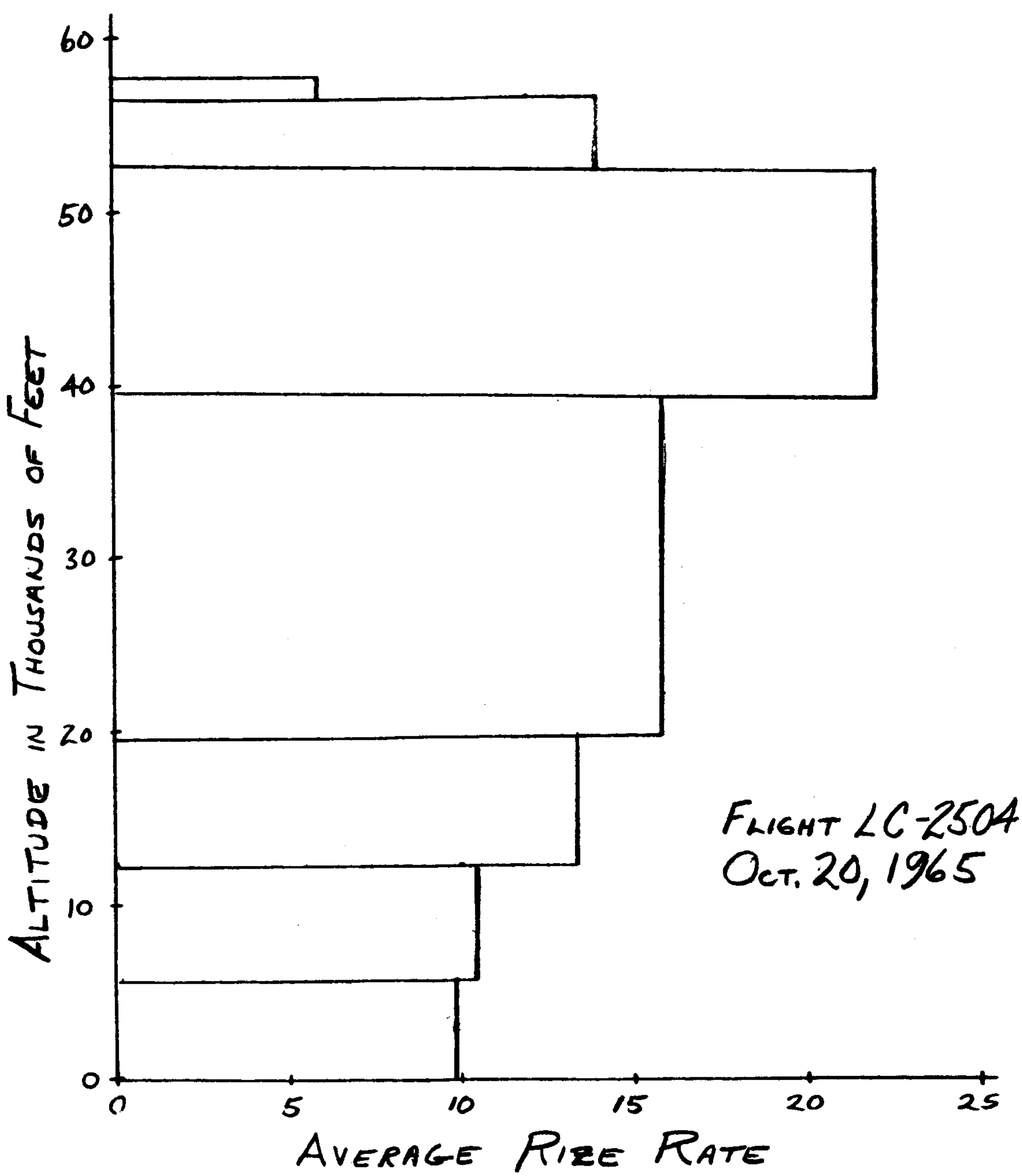


FIGURE 6

AVERAGE RISE RATE FOR SEVERAL

ALTITUDE INTERVALS ON FLIGHT LC-2504

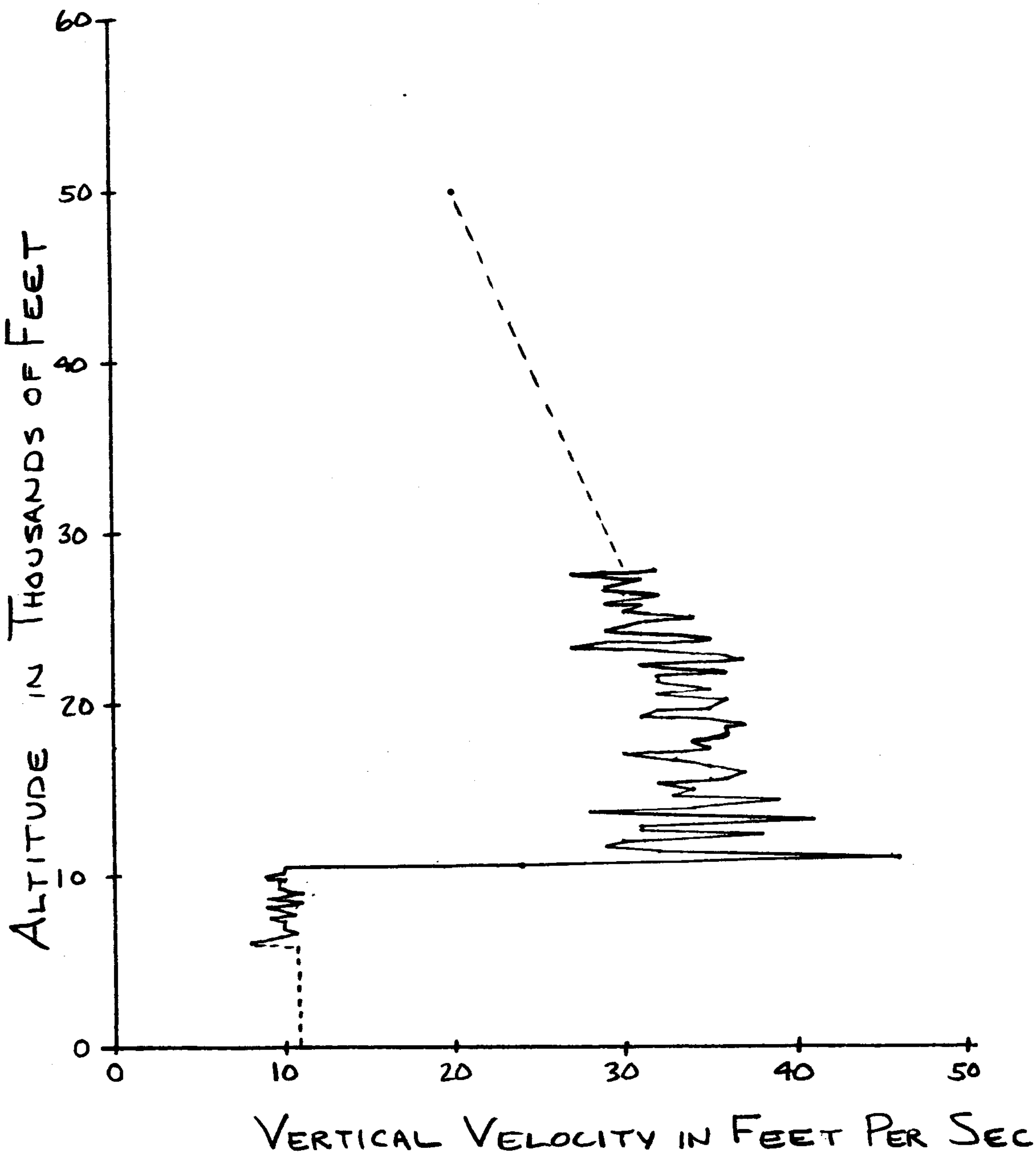


FIGURE 7

RISE RATE VERSUS ALTITUDE FOR

STREAMLINED BALLOON FLIGHT LC-2507

a maximum of 46 feet per second at 11,000 feet altitude. The directional stability of this streamlined balloon had been very good up until the time of the change in rise rate. Soon after the streamlined balloon attained the higher rates of rise it began a tight spiral motion performing two to three loops per minute. The rise rate changed as much as 5 to 10 feet per second during these spiral motions with the average rate of rise being about 35 feet per second from an altitude of 11,000 feet to 28,000 feet. Radar plot board data are not available for the period from 28,000 feet to float altitude but it is known that the streamlined balloon did attain an altitude of 50,000 feet after 43 minutes of flight. It is the belief of this investigator that the change in balloon surface shape, combined with the change in location of the balloon center-of-free-lift with altitude, accounts for the change in stability at 10,500 feet altitude. It is obvious that the balloon has not become completely stable at 28,000 feet altitude. Later examination of radar track tape data should indicate if complete stability was achieved at altitudes above 28,000 feet.

5.5 FLIGHT TEST LC-2508

This flight test was with a small 9-foot long streamlined balloon of modified C-Class shape. The balloon had a 4:1 fineness ratio, and was modified in shape primarily by use of a conical shape for the aft portion of the body and straight line segments in shape outline over the forward portion of the body as shown in Figure 2. This balloon shape was not originated for flight purposes but rather as a unit for fin structure studies. Preliminary flight tests of this unit indicated very stable flight characteristics, therefore an actual field flight test was conducted to obtain performance data. Visual observations and radar plot board data indicated completely stable flight. The rise rate versus altitude for this unit is presented in Figure 8. The initial rise rate of 34 feet per second is better than three times that obtained for initial flight of any of the other streamlined balloons tested. It should be noted here that the ratio of buoyancy to weight is only 3:1 whereas the other balloons ranged from 7.5:1 to 12.3:1 except for the hemisphere-cone balloon which failed structurally at the start of flight.

5.6 FLIGHT TEST LC-2509

This flight test was conducted with balloon number 6 modified to have the same general body shape as balloon number 7, which flew successfully. This streamlined balloon had three fins with 10 square feet of area each. This balloon also flew in a near horizontal position at time of launch and during the visual portion of the flight. At present no radar plot board data are available for analysis of the entire flight, but it is anticipated that a change in flight characteristics will be noted at some altitude.

5.7 FLIGHT TEST LC-2511

After the first few flight tests it was concluded that a streamlined balloon design was needed which located the center of buoyancy as far forward as possible. In addition it was desired that the main body should not have an efficient lift producting surface. A sphere is the most efficient shape for volume purposes and a cone would provide a nonaerodynamic body for locating the fins as far aft as possible. A special streamlined balloon designated as a hemisphere-cone design of 4:1 fineness ratio was fabricated (Figure 9) for the last flight test. An additional modification made specifically for this unit, was the use of four rather than three tail fins and the tapering or streamlining of the fins from the

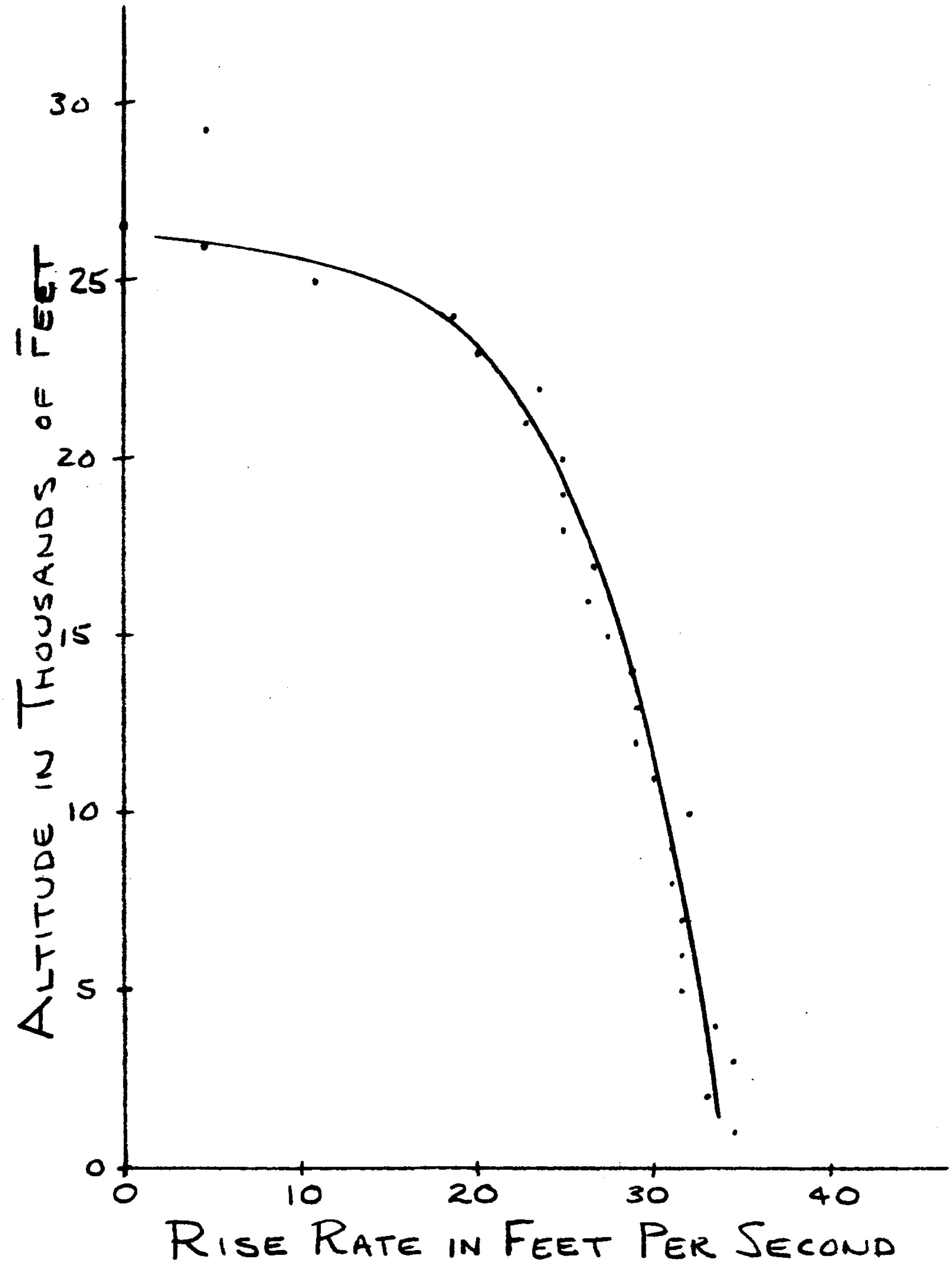


FIGURE 8

RISE RATE VERSUS ALTITUDE FOR

STREAMLINED BALLOON FLIGHT LC-2508

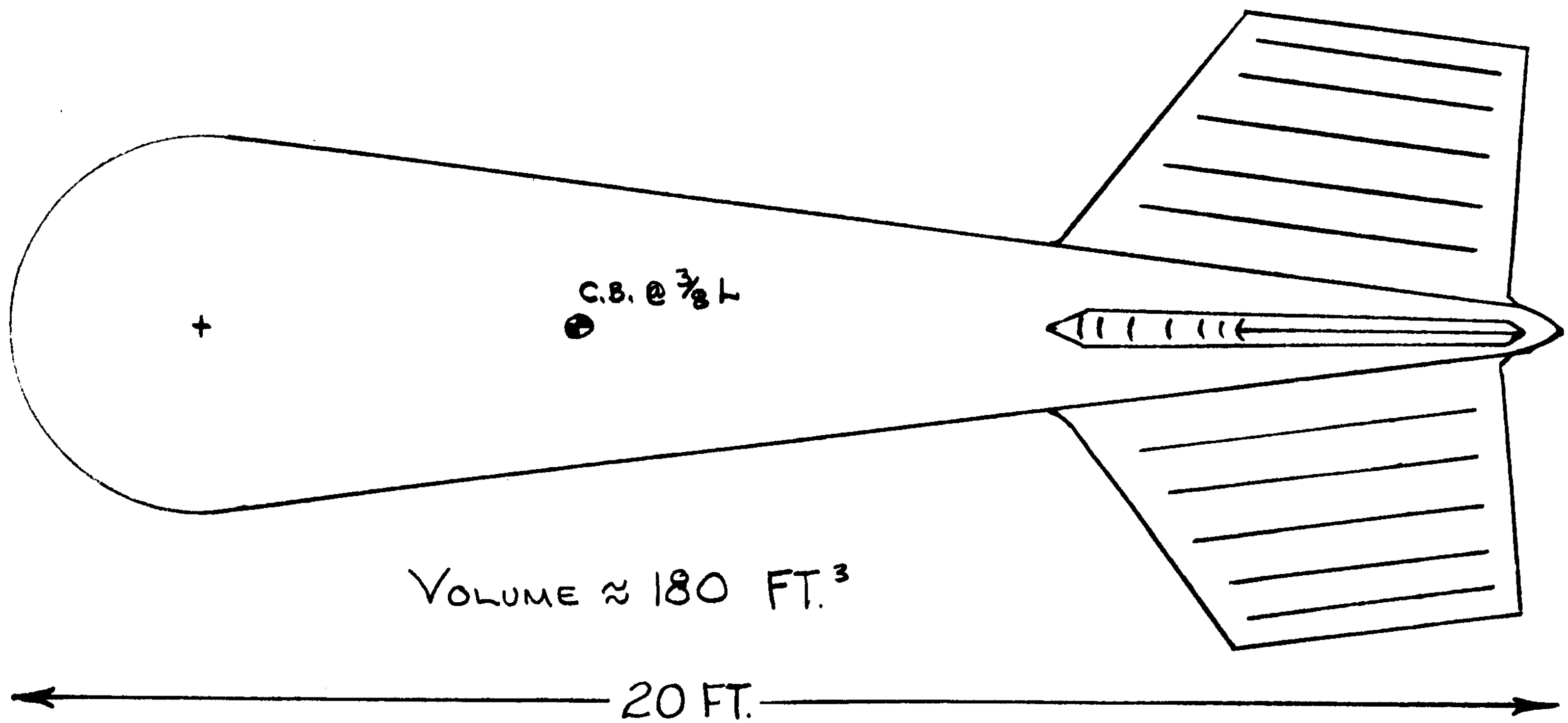


FIGURE 9

HEMISPHERE - CONE STREAMLINED

BALLOON SHAPE

leading edge to trailing edge in addition to tapering from the body to the fin tip. The actual flight test proved that the fins were not rigid enough for their area of 18 square feet each,and one fin actual tore open at the attachment point at the time of launch which resulted in failure of the the unit as a test item. This unit has been subjected to further design modifications to include web reinforcements between fins, and further flight tests are planned.

No radar plot board data of flight LC-2511 were available in time for this report.

5.8 DATA ANALYSIS

It is of interest to determine what changes would occur in location of the center-of-free-lift with altitude for a particular balloon flight. Flight LC-2504 is of special interest as a gradual change in flight conditions occurred with altitude. This particular balloon had a basic weight of 1.11 pounds. The total buoyant force was 10.62 pounds for a free lift of 9.51 pounds at ground level. The center of buoyancy was 82.9 inches from the nose. The center-of-free-lift was 80 inches from the nose at ground level but changed location with altitude as shown in Figure 10.

Figure 6 shows that the highest average rate of rise occurred between 40 and 50 thousand feet altitude. At 40 thousand feet altitude the center-of-free-lift had moved forward 11 inches from .504 L to 0.42 L. It should be noted here that the center-of-free-lift of balloon number 7 (which flew nose up all the way) was at 0.430 L at time of launch. It is also interesting to note that the center-of-free-lift of the large hemisphere-cone streamlined balloon is at 0.428 L.

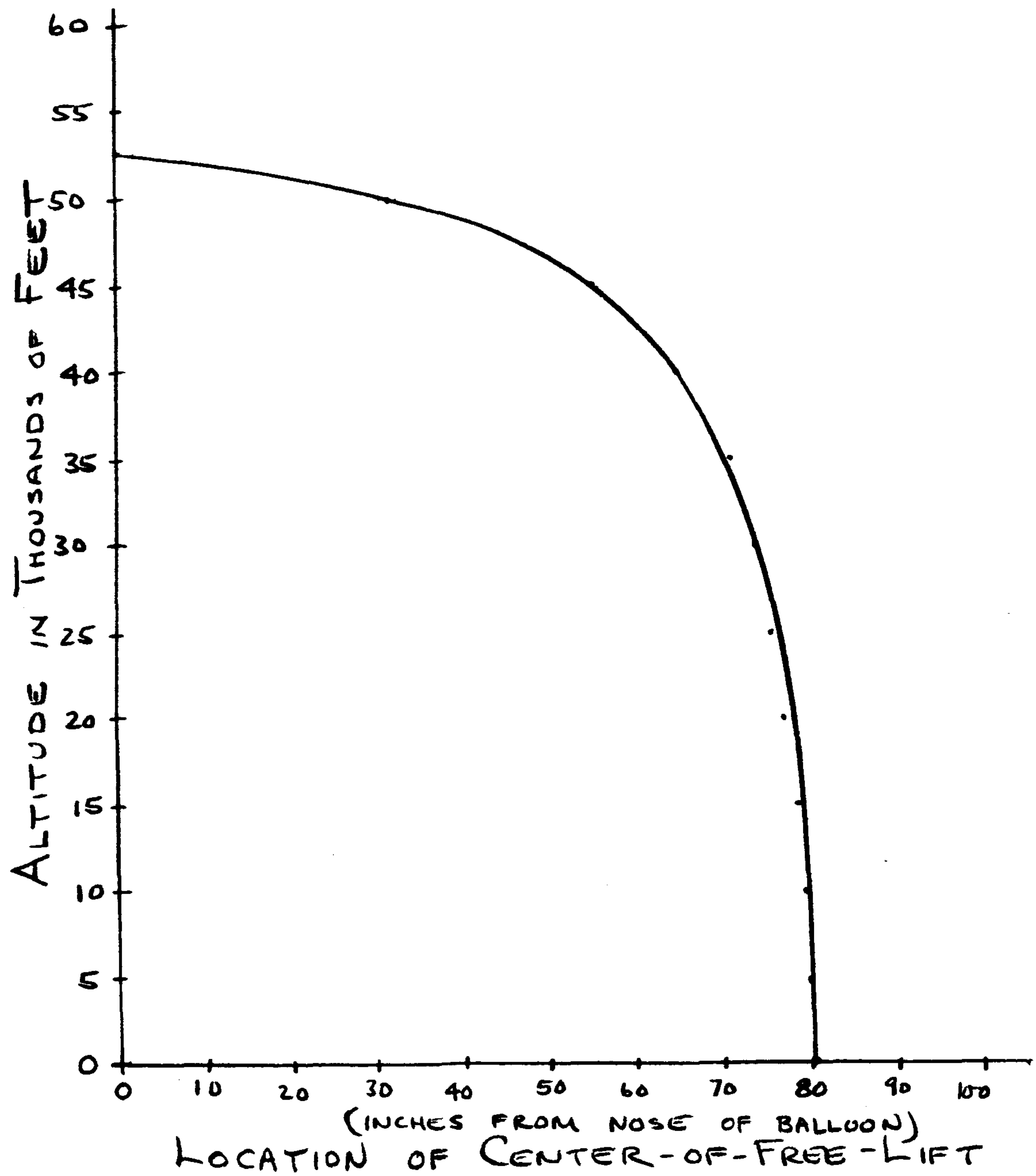


FIGURE 10 VARIATION OF LOCATION OF THE NEUTRAL MOMENT CENTER WITH ALTITUDE FOR STREAMLINED BALLOON NO. 3 USED ON FLIGHT TEST LC-2504

Detailed analysis of flight LC-2509 should be performed as soon as data are available to determine if the change in location of the center-of-free-lift to 42 per cent or less of the balloon length resulted in a noticeable change in performance.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Small streamlined balloons have been successfully flown in a stable vertical flight path at rise rates of 30 feet per second.

Larger size balloons of the same general configuration have not risen in a stable nose-up position at time of launch, yet have been subject to changes in stability with altitude.

It appears desirable that the balloon center-of-volume be as far forward as possible and that the main body should not be aerodynamically curved for lift purposes.

Base on the information that (1) the balloon center-of-free-lift (C.F.L.) is the neutral moment center and (2) that the one stable balloon configuration tested had the C.F.L. at 0.42 L, it is suggested that several streamlined balloons of one size and shape, such as the hemisphere-cone system, be fabricated and then balanced by weight addition so that the C.F.L. varies in location from approximately 0.25 L to 0.45 L. Flight test of these balloons would determine the effect of C.F.L. location on stability characteristics.

It is also of importance to determine if a streamlined balloon shape can be established that is statically and dynamically stable at zero angle of attack for the range of C. F. L. locations possible. This will be somewhat dependent on fin types and sizes. Pendulum-type wind tunnel tests of models having a C.G. location at the desired C.F.L. would give the desired data, as the C.G. is the neutral moment center for a heavier-than-air vehicle.

BIBLIOGRAPHY

Abbott, Ira H.: Airship Model Tests in the Variable Density Wind Tunnel, NACA Rept. 394, 1931.

Aeronautics Staff: Lift, Drag, N_y and N_r for C-Class Airship Hull, C. and R. Aeronautical Report Number 162, November 1920.

Aeronautics Staff: Resistance of Airship Hulls C-Class and S.S.T. Enlarged , C. and R. Aeronautical Report Number 128, April, 1919.

Bateman, H.: The Inertia Coefficients of an Airship in a Frictionless Fluid, NACA Rept. 164, 1923.

Burgess, C.P.: Flight Tests on U.S.S. Los Angeles Part II - Stress and Strength Determination, NACA Rept. 325, 1929.

Burgess, C.P.: Forces on Airships in Gusts, NACA Rept. 204, 1924.

Crocco, G. A.: Effect of Ratio Between Volume and Surface Area of Airships, NACA TN 280, September 1924.

Crowley, J. W., Jr. and DeFrance, S.J.: Pressure Distribution on the C-7 Airship, NACA Rept. 223, 1926.

DeFrance, S. J. and Burgess, C.P.: Speed and Deceleration Trials of U.S.S. Los Angeles, NACA Rept. 318, 1928

DeFrance, S.J.: Flight Tests on U.S.S. Los Angeles Part I - Full-Scale Pressure Distribution Investigation, NACA Rept. 324, 1928.

Evans, George R.: Aerodynamic Characteristics of Bodies of Revolution With Fins; An Annotated Bibliography, Lockheed M. and S. Company Report 8-40-63-10-SB-63-76, July 1963. N64-23880.

Evans, George R.: Aerodynamic Characteristics of Bodies of Revolution Without Fins; An Annotated Bibliography, Lockheed Report 8-4-63-13 - SB-63-75, July 1963. N64-27793.

Freeman, Hugh B.: Measurements of Flow in the Boundary Layer of a 1/40-Scale Model of the U.S. Airship Akron, NACA Rept. 430, 1932.

Freeman, Hugh B.: Pressure-Distribution Measurements on the Hull and Fins of a 1/40-Scale Model of the U.S. Airship Akron, NACA Rept. 443, 1932.

Havill, Clinton H.: The Drag of Airships, NACA TN 247, September 1926.

Havill, Clinton H.: The Drag of Airships - II - Drag of Bare Hulls, NACA TN 248, October 1926.

Heaslet, Max A. and Nitzberg, Gerald E.: The Calculation of Drag for Airfoil Sections and Bodies of Revolution at Subcritical Speeds, NACA RM 27B06, April 1947.

Higgins, George J.: Tests of the N.P.L. Airship Models in the Variable Density Wind Tunnel, NACA TN 264, September 1927.

Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Fuselage Stability in Yaw With Various Arrangements of Fins, NACA TN 785, November 1940.

Kaplan, Carl: Circular Motion of Bodies of Revolution, NACA TN 554, February 1936.

Kapteyn, A.: Principle of the Boerner Airship, NACA TN 154, November 1922.

Lotz, I.: Calculation of Potential Flow Past Airship Bodies in Yaw, NACA TN 675, July 1932.

McHugh, James G.: Pressure-Distribution Measurements at Large Angles of Pitch on Fins of Different Span-Chord Ratio on a 1/40-Scale Model of the U.S. Airship Akron, NACA Rept. 604, 1937.

Munk, Max M.: The Aerodynamic Forces on Airship Hulls, NACA Rept. 184, 1924.

Munk, Max M.: The Choice of the Speed of an Airship, NACA TN 89, March 1922.

Munk, Max M.: The Drag of Zeppelin Airships, NACA Rept. 117, 1921.

Munk, Max M.: Notes on Aerodynamic Forces - I - Rectilinear Motion, NACA TN 104, July 1922.

Munk, Max M.: Notes on Aerodynamic Forces - II - Curvilinear Motion, NACA TN 105, July 1922.

Munk, Max M.: Notes on Aerodynamic Forces - III - The Aerodynamic Forces on Airships, NACA TN 106, July 1922.

Naatz, H.: Recent Researches in Airship Construction - I - Forces of Flow on a Moving Airship and the Effect of the Control Surfaces, NACA TN 275, August 1924.

Naatz, H.: Recent Researches in Airship Construction - II - Bending Stresses on an Airship in Flight, NACA TN 276, August 1924.

Naatz, H.: Recent Researches in Airship Construction - III - A New Type of Nonrigid Airship, NACA TN 277, September 1924.

Rizzo, Frank: A Study of Static Stability of Airships, NACA TN 204, September 1924.

Robinson, Russell G. and Wright, Ray H.: Estimation of Critical Speeds of Airfoils and Streamlined Bodies, ACR (WR L-781), March 1940.

Schubauer, G.B.: Air Flow in a Separating Laminar Boundary Layer, NACA Rept. 527, 1935.

Stahl, Friedrich: Rigid Airships, NACA TN 237, November 1923.

Stapfer, Lt.: Comparison of Nonrigid and Semirigid Airships, NACA TN 163, November 1922.

Terry, John E.: Aerodynamic Characteristics of Ring Wings; A Bibliography , Redstone Scientific Information Center, U.S. Army Missile Command, Redstone Arsenal, Alabama, RSIC-285, AD-452725, N65-14220, September 1964.

Thompson, F.L.: Full-Scale Turning Characteristics of the U.S.S. Los Angeles, NACA Rept. 333, 1929.

Thompson, F. L. and Kirschbaum, H. W.: The Drag Characteristics of Several Airships Determined by Deceleration Tests, NACA Rept. 397, 1931.

Tuckerman, L. B.: Notes on Aerodynamic Forces on Airship Hulls, NACA TN 129, March 1923.

Von Karman, Theodor: Calculation of Pressure Distribution on Airship Hulls, NACA TN 574, July 1930.

Warner, Edward P.: The Future of the Airship, NACA TN 121, July 1922.

Wieselsberger, C.: Air Forces Exerted on Streamlined Bodies With Round or Square Cross-Section When Placed Obliquely to the Airstream, NACA TN 267, June 1924.

Zahm, A.F. and Smith, R.H., "Drag of Two NPL Airship Models", C. and R. Aeronautical Report Number 206, November 1920.

Zahm, A.F., Smith, R.H. and Hill, G. C.: The Drag of C-Class Airship Hull with Varying Length of Cylindric Midships, NACA Rept. 138, 1921.

REFERENCES

1) Zahm, A. F., Smith, R. H. and Louden, F. A.: Air Forces, Moments and Damping on Model of Fleet Airship Shenandoah, Rept. 215, September 1925.

2) Freeman, Hugh B.: Force Measurements on a 1/40-Scale Model of the U.S. Airship Akron, NACA Rept. 432, 1932.

3) Zahm, A. F., Smith, R. H. and Louden, F. A.: Drag of C-Class Airship Hulls of Various Fineness Ratios, NACA Rept. 291, 1928.

4) Von Mises, Richard: Theory of Flight, Dover Publications, Inc., New York, New York, 1959.

5) Menke, James A.: Capabilities of Captive Balloon Systems, Paper presented at Air Force Cambridge Research Laboratories Scientific Balloon Symposium, September 1963.

6) Bairstow, L.: Applied Aerodynamics. Second Edition, Longmans, Green and Co., London and New York, 1939 p.77.

7) Upson, Ralph H. and Klikoff, W. A.: Application of Practical Hydrodynamics to Airship Design, NACA Rept. 405, 1931.

8) Anderson, A. A., Erickson, M. L.; Frochlich, H. E.; Henjum, H. E.; Schwoebel, R. L.: Stone, V. H.; and Torgeson, W. L.: Lighter-Than-Air Concepts Study, AD 236 988, March 1960.